Year: 2018

Retrospective evaluation of the efficacy of minimally invasive, fluoroscopic-assisted reduction and stabilisation of unicondylar humeral fractures

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Abstract: OBJECTIVE:This study evaluated the proficiency in executing closed, fluoroscopic-assisted reduction of unicondylar humeral fractures. The following were hypothesised: experienced surgeons would be highly successful in performing closed reduction; body weight, time to surgery and surgeon experience would influence the reduction method; and the reduction method would not affect technical aspects of the repair. METHODS: All unicondylar humeral fractures stabilised between January 2007 and January 2017 were reviewed. Signalment and time to surgery, experience of the attending surgeon, and the initial and definitive reduction methods were recorded. Initial and subsequent postoperative radiographs were used to assess fracture reduction, implant placement and complications. Univariate polychotomous logistic regressions, Fisher's exact test, Kruskal-Wallis rank sums non-parametric test or equivalence tests were used to compare parameters evaluated based on the approach employed ($P < 0.05$ significant). RESULTS:A total of 36 dogs with 37 fractures were identified (median weight: 5.4 kg; median time to surgery: 3 days). Of these, 11 of 15 attempted closed reductions were successful. Successful closed reductions had shorter times to surgery than limited open or open reductions ($P = 0.009$). Age, weight and surgeon experience did not influence the definitive reduction method. Technical aspects of reduction and stabilisation were similar among the reduction methods. Surgery times were shorter for closed reductions ($P = 0.034$). Of the fractures, 75% healed without complications and 85% had excellent long-term function. CONCLUSION: The results suggested that closed, fluoroscopic-assisted reduction is a proficient (73% successful) and efficient (shorter surgery times with comparable technical results compared with other limited open and open reduction) means of stabilising acute unicondylar humeral fractures.

DOI: https://doi.org/10.1111/avj.12723

Originally published at:
Au Yong, J A; Lewis, D D; Evans, R B; Kim, S E; Pozzi, Antonio (2018). Retrospective evaluation of the efficacy of minimally invasive, fluoroscopic-assisted reduction and stabilisation of unicondylar humeral fractures. Australian Veterinary Journal, 96(8):302-307.
DOI: https://doi.org/10.1111/avj.12723

A retrospective evaluation of the efficacy of minimally invasive, fluoroscopic- assisted reduction and stabilization of uni-condylar humeral fractures

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Last edited by JA June 7, 2017

Abstract

Efficacy in executing closed, fluoroscopic-assisted stabilization of 37 uni-condylar humeral fractures was evaluated. Closed reductions had shorter times to surgery, and shorter surgery times, than limited open or open reductions. Age, weight, and surgeon experience did not influence reduction method. Technical aspects of the repair were similar amongst reduction methods.

During the past 2 decades, there has been an emphasis on employing minimally invasive techniques for managing fractures in dogs (Beale & Pozzi 2012; Cook et al. 1999; Tomlinson 2012; Leasure et al 2007; Wheeler et al. 2007; Tonks et al. 2008). Closed or limited open fracture reduction methods have been advocated with the purported benefits of minimizing iatrogenic trauma, preserving blood supply to the fracture site, decreasing the risk of infection, and providing earlier return to function (Aron et al. 1995; Harari et al. 1996; Johnson et al. 1996; Hudson et al. 2009). While considerable attention has been focused on minimally invasive approaches in managing diaphyseal long bone fractures (Guiot & Dejardin 2011; Schmokel et al. 2007; Pozzi et al. 2012; Baroncelli et al. 2012; Beale & McCally 2012), several reports have described minimally invasive approaches for articular fractures (Cook et al. 1999; Leasure et al 2007; Tomlinson 2012, Tonks et al. 2008, Jones et al. 2015; Guille et al. 2004; Lanz et al. 1999; Hudson & Pozzi 2012).

We have considerable experience with minimally invasive fracture stabilization at our institution (Hudson et al. 2012; Pozzi et al. 2013; Pozzi et al. 2012; Leasure et al. 2007, Jones et al. 2015, Wheeler et al. 2007; Pozzi & Lewis 2009; Baroncelli et al. 2012; Garofolo & Pozzi 2013; Boekhout-Ta et al. 2017; Guille et al. 2004; Lanz et al. 1999; Hudson & Pozzi 2012) and we have performed fluoroscopic-assisted closed reduction of uni-condylar humeral fractures for nearly 2 decades (Guille et al. 2004; Lanz et al. 1999). The objective of this study as to assess our proficiency in executing closed reduction and stabilization of uni-condylar humeral fractures. In addition, we wanted to assess if specific patient parameters or surgeon experience influenced the reduction method performed. We also want to assess the technical outcome of fractures stabilized via either closed or open reductions. We hypothesized that surgeons experienced in minimally invasive orthopedic procedures would be highly successful in stabilizing uni-condylar humeral fractures via closed reduction. We also hypothesized that age, body weight, and the time from injury to surgery as well as surgeon experience would influence the method of reduction (closed versus open) employed. Our final hypothesis was that the method of reduction employed would not affect technical aspects of the surgical repair and the occurrence of complications.

Materials and Methods

The medical records, including radiographs, of all dogs undergoing uni-condylar humeral fracture stabilization at the University of Florida Small Animal Hospital (UF SAH) between January 2007 and January 2017 were reviewed. Each dogs' signalment, including body weight, and the time from injury to surgery were recorded. Radiographs were reviewed to characterize each fracture, whether the fracture involved the capitulum or trochlea, if the distal humeral physis was radiographically evident, and if comminution was present.

Surgical Technique

The primary surgeon performing each procedure was categorized as a board-eligible or board-certified faculty surgeon experienced in performing minimally invasive orthopedic procedures, or a faculty surgeon or resident less experienced in these techniques. Operative reports were reviewed to determine what reduction technique was initially attempted as well as what reduction technique was eventually used to complete the procedure. Of particular interest was if a closed reduction was initially attempted: was the fracture definitely stabilized closed or converted to a limited open reduction or open reduction.

Closed reduction was defined as extracorporeal manipulation of the fractured condylar segment without making an incision to facilitate reduction, with application of implants performed via small (typically $\leq$ 1 cm) insertion incisions. Limited open reduction was defined as making an incision exposing the epicondyle of the fractured condylar segment extending proximally along the epicondylar ridge to allow direct visualization of the fracture margins in the metaphyseal region to confirm reduction (Fossum 2013). With the limited open approach, trans-condylar implants were inserted through the exposed abaxial surface of the condyle (Piermattei

& Johnson 2004). Open reduction was defined as exposing the majority of the abaxial portion of the involved condylar segment and ipsilateral metaphysis including elevation of the extensor carpi radialis muscle and performing a craniolateral arthrotomy to expose the cranial aspect of the proximal articular surface of the condyle to confirm reduction in fractures involving the capitulum. With fractures that involved the trochlea, an incision was made over the medial distal humerus. The brachial artery and vein, and median nerve were isolated and protected cranially,and the ulnar nerve and collateral ulnar vessels were isolated and retracted caudally. The anconeal muscle was elevated from its insertion on the caudomedial aspect of the trochlea to access the fracture (Piermattei et al. 2006). Trans-condylar screws were placed by initially drilling a glide hole from the fractured surface of the free fracture segment when an open approach was performed. The fracture was then reduced before completing the process of screw placement (Tobias & Johnston; Piermattei et al. 2006).

Regardless of the approach utilized, reduction was maintained by placing either Vulsellum (Jacobs Vulsellum Forceps; Sklar Surgical Instruments; West Chester PA) or point-to-point forceps (Reduction Forceps with points; DePuySynthes Vet; West Chester PA) across the condyle. Temporary or sometimes permanent adjunctive, trans-condylar Kirschner wires were placed to help maintain reduction (Piermattei et al. 2006). The condyle was stabilized with either an interfragmentary trans-condylar screw or an Orthofix pin (Orthofix Fragment Fixation System, Verona, Italy). Placement of trans-condylar Kirschner wires subsequently over-drilled using cannulated drill bits (Drill Bit, Cannulated, Arthrex, Inc. Naples, FL 34108; Cannulated Drill Bit, Synthes, West Chester, PA 19380) was frequently used to facilitate proper screw placement. Screws were typically placed in lag fashion. The metaphyseal component of the fractures was stabilized using either an interfragmentary Kirschner wire or an adjunctive epicondylar plate and screws. Intraoperative fluoroscopy (Siremobil Compact Fluoroscope; Siemens, Iselin, NJ; Insight 2 Mini, Hologic, Inc. Marlborough MA 01752; Vision 2 FD, Ziehm Imaging Inc., Orlando FL 32822) was used to assess reduction and implant placement. The time of surgery was obtained from the anesthetic record.

Radiographic Assessment

Post-operative radiographs were reviewed to assess fracture reduction (Cook et al., Morgan et al.). Any step or gap at the articular surface humeral condyle was measured individually, and recorded to the nearest mm. Any step or gap in the metaphyseal region of the fracture was measured and the combined measurements were recorded to the nearest mm. Implant placement was evaluated and deemed as acceptable or inappropriate if an implant penetrated the articular surface of the condyle. The length of the tip of the primary trans-condylar implant which protruded from (recorded as a positive number) or failed to engage the trans-cortex of the condyle (recorded as a negative number) was recorded in mm. Trans-condylar implant angulation was measured by comparing the angle of intersection between a line drawn through the core axis of the primary implant stabilizing the condyle and a line drawn through the apices of the medial and lateral condyles (Morgan et al. 2008). Angles formed by lines that converged opposite the fractured portion of the condyle were designated as positive. Angles formed by lines that diverge opposite to the fractured portion of the condyle were designated as negative.

Radiographs obtained at subsequent post-operative follow-up examinations were evaluated to determine when the fractures had obtained union and for the development of complications. Complications were effectively managed by administration of medications or simple removal of implants in fractures that healed without loss of reduction were considered minor (Cook et al. 1999). Complications that resulted in a loss of reduction, necessitated a revision surgery or resulted in poor long-term functional outcomes were considered major (Cook et al. 1999).

Long-term Follow-up Owner Assessment

Owners were contacted by telephone to assess their perception of their dog's limb function and if any complications arose after to their dog's final evaluation at the UF SAH. Owners were asked to assess their dog's use of the operated limb and if their dog required any medications to specifically address problems ascribed to the dog's elbow fracture. Owners were also asked to rate their satisfaction with the result of surgery.

Statistical Methods

The data were summarized with descriptive statistics and distributions to check for spurious observations and provide reportable statistics. Exploratory univariate polychotomous logistic regressions or Fisher's exact tests (depending on if the independent variable was continuous or discrete) were used to determine if age, weight, time from injury, and surgeon experience influenced the final reduction method employed. $P < 0.05$ was considered significant.

Two statistical methods were used to assess if there was a significant difference in surgery times between closed and limited open or open reduction. First, the Kruskal-Wallis rank sums nonparametric test was used to compare surgical times for the reduction methods. For that test, $P < 0.05$ means that the data are consistent with the reduction methods having different medians.

Equivalence tests were used to compare closed reduction to limited open and open reduction (combined) for the presence of a post-operative step and/or gap at the articular surface of the humeral condyle, the presence of a step and/or gap in the metaphyseal region, screw angulation, and screw length. Equivalence tests assess the scientific hypothesis that there is only a small difference between the group means. That is, the means are close enough to each other to be functionally similar, but not necessarily identical. That similarity distance, called delta, is defined before the analysis. For this study, the deltas were the standard deviations of the outcomes for the open reduction method. For an outcome (e.g., implant length), an equivalence test returning $P < 0.05$ signifies that the data are consistent with the reduction methods having means that are functionally close together, within delta, the standard deviation of fractures stabilized via the open reduction method. In other words, for $P < 0.05$, the data are consistent with the closed reduction outcome mean falling within one standard deviation of the limited open and open reduction (combined) outcome mean.

Results

Thirty-six dogs [11 males, 4 castrated males, 14 females, 7 spayed females] were identified that meet the inclusion criteria (Table 1). One dog had bilateral uni-condylar humeral fractures, resulting in 37 fractures. Dogs ranged in weight from 1.1-25.4 [mean ± SE: 7.9 ± 1.1; median: 5.4] kg. Age of the dogs ranged from 4–120 [mean 24 ± 6; median: 5] mo. The fracture involved the capitulum in all but 3 dogs. The distal humeral physis was identifiable in 26 fractures. Five fractures had comminution of the epicondylar ridge.

The duration of time lapsed from when the dog sustained the fracture to the time of surgery ranged from 0-18 [mean ± SE: 4.1 ± 0.7; median: 3] d. Surgeons experienced in minimally invasive orthopedic surgery repaired 24 fractures. Closed reduction was attempted in 15 fractures (11 by experienced surgeons), and was successful in 11 fractures (8 by experienced surgeons). Three of the closed reductions were converted to limited open reductions, while 1 closed was converted into an open reduction. Limited open reductions were attempted in 8 fractures, but 1 of these fractures was converted into an open reduction. A total of 26 fractures were definitely stabilized via a limited open or open reduction. Fractures that were reduced and stabilized via closed reduction had a shorter time from injury to surgery, followed by limited open reduction, then open reduction. This was the only factor that affected method of reduction initially attempted ($P = 0.009$). Age, weight, and surgeon experience did not affect the initial or definitive method of reduction.

A screw was used as the primary trans-condylar implant in 25 fractures. An Orthofix pin was used as the primary trans-condylar implant in 12 fractures (Table 2). The end of the trans-condylar implant protruded through the trans-cortex of the intact portion of the condyle [mean ± SE: 1.8 ± 0.3 mm; median: 2.0 mm] in all but 10 fractures. Trans-condylar implant angulation ranged from -8 to +23 [mean ± SE: 5.8 ± 1.2; median: 5] degrees. The trans-condylar Orthofix pin inadvertently penetrated the articular surface of the condyle in 1 fracture and was subsequently replaced with an appropriately positioned screw. Kirschner wires were used for supplemental metaphyseal fixation in 29 fractures and an adjunctive epicondylar plate and screws were used in 7 fractures. Anatomic reduction was achieved in 12 fractures without a step or gap at the articular surface. For the statistical analysis of the technical aspects of the reduction and stabilization, fractures stabilized via a closed reduction were compared to fractures stabilized via both a limited open reduction and open reduction combined (Table 3). The gap at the articular surface (P = 0.042), step and/or gap at the metaphyseal surface (P = 0.020), implant angulation (P = 0.007), and implant length (P = 0.034) were similar between reduction groups. A step at the articular surface was only technical parameter assessed that was not statistically equivalent between reduction methods (P = 0.055). However, the difference in average step was 0.27, which is well below the 0.7 threshold. This gives an indication that the technical aspects of reduction and stabilization were similar irrespective of which reduction technique was employed. Surgery time ranged from 60 - 240 (median: 118) minutes. Closed reductions had significantly shorter surgery times (median: 75 minutes) compared to limited open reduction (median: 145 minutes) and open reductions (median: 133 minutes) (P = 0.016).

The owners of 16 dogs were successfully contacted via telephone to obtain long-term follow-up information [range: 1 – 128; mean ± SE: 40 ± 12; median: 19 mo]. The owners of 14 dogs felt their dog had excellent limb function. None of these 14 dogs required medications to address pain or lameness related to the fractured elbow and of the all owners were very satisfied with the outcome of the surgery. Two dogs reportedly had intermittent lameness within the last 6 mo of being contacted. The owner of 1 of these dogs declined a request to re-evaluate their dog at our institution, and the other dog had recently been euthanized due to unrelated health issues a few months after the lameness developed. The owners of remaining 19 dogs could not be contacted.

Discussion

Our results suggests that minimally invasive, fluoroscopic-assisted reduction is a reasonably proficient means of stabilizing uni-condylar humeral fractures. Closed reduction was initially attempted in 15 fractures and successfully executed in 73% of these cases. Time from injury to surgery was the only parameter identified that significantly affected the decision to attempt or successfully execute a closed reduction. Surgeons were more likely to attempt closed reduction if surgery was performed within 72 h of the dog sustaining its fracture. The lone exception being a closed reduction which was successfully performed by an experienced surgeon on a fracture that had been sustained 7 d prior to surgery. Age, and surprisingly weight and surgeon experience were not determined to affect the method of reduction chosen.

Fractures managed in a closed fashion had shorter surgery times compared to fractures stabilized via a limited open or open reduction. If the attempted reduction was deemed satisfactory based on fluoroscopy, implant placement and closure of the implant insertion incisions proceeded rapidly. Shorter duration of surgery has a number of advantages and has been associated with a decreased risk of surgical site infections (Eugster et al. 2004), in addition to reduced anesthesia time and associated costs. Realignment of the articular surface was actually superior in fractures that were stabilized via a closed reduction. The average difference in the step at the articular surface between reduction techniques was admittedly small (0.27 mm) and is unlikely to influence the clinical outcome of surgery (Guille et al.). The remaining technical aspects of the repairs outcomes that we evaluated were equivalent amongst the 3 reduction techniques. Our results are encouraging, as fractures stabilized via a closed reduction had comparable reductions and implant placement to fractures that were stabilized in a limited open or open fashion. Based on our findings, we would advocate initial attempting closed reduction when stabilizing uni-condylar humeral fractures in dogs.

We achieved anatomic reduction in 32% of our fractures, without a step or gap at the articular surface, while previous studies have reported 33% - 55% success in obtaining accurate reduction (Morgan et al. 2008; Cook et al. 1999; Guille et al. 2004). Of the 28 fractures that had adequate clinical and radiographic follow-up evaluations, 75% healed without complications, 14% healed with minor complications. Our minor complication rate was lower than that reported in other studies assessing uni-condylar humeral fractures stabilized via limited open or open reduction (21–35%)(Guille, Morgan, Cinti), and comparable to that reported by Cook et al. (9%) in which fractures were stabilized in a closed fashion. Our major complication rate of 11% was higher than that reported in other studies (0 – 3%) in which uni-condylar humeral fractures were stabilized by either limited open or open reduction (Cinti et al., Guille et al.), but was comparable to that reported in Cook et al. (1999) (9% major complication rate). Future studies assessing the efficacy of closed, or open reductions for the surgical stabilization of uni-condylar humeral fractures in dogs would benefit from the use of a standardized definition for fracture union as well as major and minor complications.

Eighty-eight percent of dogs that we were able to obtain long-term owner assessment of function had excellent limb use with no evidence of lameness. These results are comparable to those reported by Guille et al. (2004) (77% of dogs that returned for long-term evaluations), Morgan et al. (2008) (79% of dogs in owner-assessed clinical outcome), and Cinti et al. (2017) (92% at long-term evaluation) and superior to that reported by Cook et al. (1999) (67% at final follow-up evaluation). Our results corroborate that dogs which undergone uni-condylar humeral fracture stabilization have a good prognosis for excellent return to function, and this was also reflected in the owners' satisfaction with the outcome of the surgery. Additional objective measurements and follow-up assessments would be warranted to determine if owner-assessment correlated to actual limb function.

As with all retrospective studies, there are a number of limitations that need to be considered when interpreting our results. We encountered challenges in retrieving complete medical records due to the decade long study-period. There was also a lack of any clinical and radiographic follow-up information beyond discharge for 24% of our cases. The number of dogs assessed in this study was small, raising concerns regarding a to potentially lack of power in achieving statistical significance when considering factors such as age, weight, surgeon experience in influencing the method of reduction initially attempted.

Our results support a recommendation for initially attempting closed reduction of relatively recently sustained (<72 hours) uni-condylar humeral fractures in institutions which have intra-operative fluoroscopy available. We found that closed reduction of these fractures resulted in a shorter duration of surgery and yielded similar technical outcomes, compared to fractures stabilized via a limited open or open reduction. Future prospective clinical studies are warranted to further evaluate the efficacy of closed fluoroscopic-assisted reduction of uni-condylar humeral fractures in dogs. Consideration should be given to developing multi-institutional prospective studies to generate meaningful case numbers.

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Tables

Table 1: Clinical parameters pertaining to initial and definitive reductions used to stabilize 37 uni-condylar humeral fractures in 36 dogs. Values reported as mean ± standard error; range.

Reduction Method		Number of Fractures	Dog's Age (months)	Dog's Weight (kg)	Time from Injury to Surgery (days)	Attending Surgeon	
						Experienced	Less Experienced
Closed	Initial	15	22.8 ± 9.7; 3.6 – 108.0	8.6 ± 1.6; 2.3 – 23.3	1.6 ± 0.3; 0 – 3.0	11	4
	Definitive	11	13.8 ± 8.3; 3.0 – 96.0	8.4 ± 1.5; 2.3 – 18.0	1.7 ± 0.3; 1.0 – 3.0	8	3
Limited Open	Initial	8	27.5 ± 15.7; 3.0 – 120.0	4.2 ± 1.3; 1.5 – 9.7	4.5 ± 1.1; 1.0 – 7.0	4	4
	Definitive	10	32.3 ± 15.2; 3.0 – 120.0	7.2 ± 2.5; 0.3 – 10.0	3.7 ± 1.2; 0.0 – 7.0	5	5
Open	Initial	14	21.3 ± 9; 3.0 – 96.0	8.7 ± 1.9; 1.1 – 25.4	6.0 ± 1.4; 1.0 – 18.0	9	5
	Definitive	16	24.6 ± 8.8; 3.0 – 96.0	7.9 ± 1.8; 1.1 – 25.4	5.6 ± 1.3; 1.0 – 18.0	11	5

Table 2: Clinical and radiographic parameters, final reduction method performed, and outcomes for 36 dogs undergoing uni-condylar humeral fracture stabilization. Values reported as mean ± standard error; range.

Definitive Reduction Method	Number of Fractures	Surgery Time (min)	Articular Step (mm)	Articular Gap (mm)	Metaphyseal Step and/or Gap (mm)	Transcondylar Implant				Complications	
						Screw	Orthofix Pin	Protrusion (mm)	Angulation (°)	Minor *	Major +
Closed	11	90 ± 10; 60 – 146	0.3 ± 0.1; 0.0 – 1.0	0.4 ± 0.2; 0.0 – 1.0	1.3 ± 0.3; 0.0 – 3.0	7	4	1.2 ± 0.6; -2.0 – 5.0	5 ± 2; -3 – 13	2	0
Limited Open	10[a]	146 ± 21; 75 – 240	0.5 ± 0.2; 0.0 – 2.0	0.5 ± 0.2; 0.0 – 1.0	1.1 ± 0.2; 0.0 – 2.0	8	2	2.6 ± 0.6; 0.0 – 5.0	6 ± 3; -1 – 23	1	0
Open	16[b,c]	141 ± 11; 75 – 240	0.6 ± 0.2; 0.0 – 3.0	0.8 ± 0.2; 0.0 – 2.0	1.8 ± 0.3; 1.0 – 4.0	10	6	1.7 ± 0.5; -1.0 – 5.0	6 ± 2; -8 – 18	1	3

[a]Three fractures were converted from attempted closed reduction.

[b]One fracture was converted from attempted closed reduction.

[c]One fracture was converted from attempted limited open reduction.

*Complications that healed without loss of reduction and fixation and was effectively managed by administration of medications or simple removal of one or more implants without loss of fracture reduction.

[+] Complications that resulted in a loss of reduction and fixation, necessitated a revision surgery, or had poor long-term functional outcomes.

Table 3: Statistical analysis of technical aspects of reduction and fixation (closed reduction versus limited open or open reduction) of 36 dogs [37 fractures] undergoing uni-condylar humeral fracture repair

Variable	**delta**	**P-value**
Step at the articular surface	.7	0.055
Gap at the articular surface	.7	0.042
Step and/or gap in the metaphyseal region	1	0.020
Screw angulation	8	0.007
Screw length	2.2	0.034